Grand Challenges for Engineering & Grand Challenges Scholars Program

University Materials Council
Phoenix, Arizona
12th March 2018

B.L. Ramakrishna
Director, GCSP Network
National Academies of Science, Engineering and Medicine

The Takeaways

Grand Challenges for Engineering

- where did they come from and why?

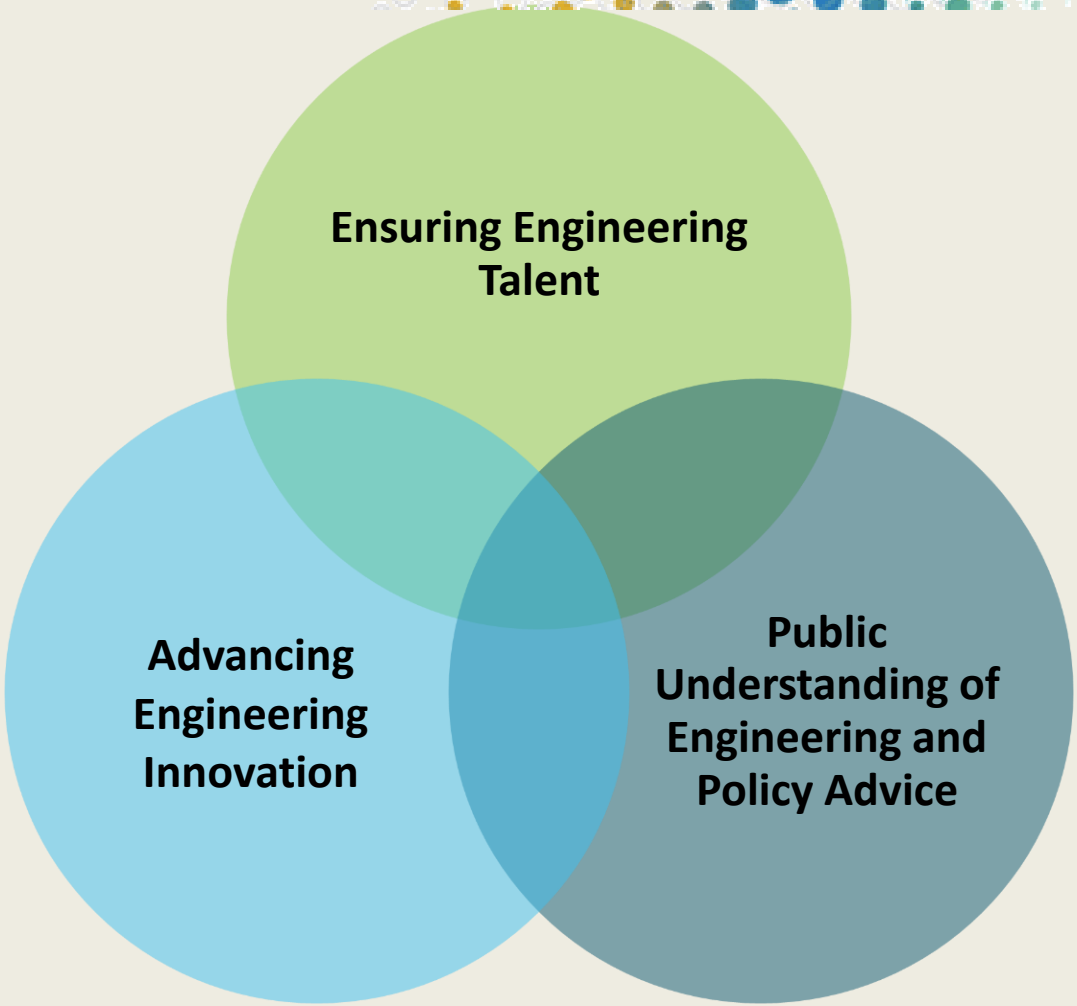
Grand Challenges Scholars Program

- Value of a broad education to prepare the "global engineer" to address global grand challenges

The Opportunity for MSE

- Interdisciplinary, Agnostic, Relevance

The National Academies of | SCIENCES ENGINEERING MEDICINE



George Constable and Bob Somerville

A CENTURY OF INNOVATION

Twenty Engineering Achievements That Transformed Our Lives

Foreword by

NEIL ARMSTRONG

Afterword by

ARTHUR C. CLARKE

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20th Century's Greatest Engineering Achievements

1. Electrification
2. Automobile
3. Airplane
4. Water supply and distribution
5. Electronics
6. Radio and television
7. Agricultural mechanization
8. Computers
9. Telephone
10. Air conditioning/refrigeration
11. Interstate highways
12. Space flight
13. Internet
14. Imaging
15. Household appliances
16. Health technologies
17. Petrochemical technology
18. Laser and fiber optics
19. Nuclear technologies
20. High-performance materials

http://www.greatachievements.org/

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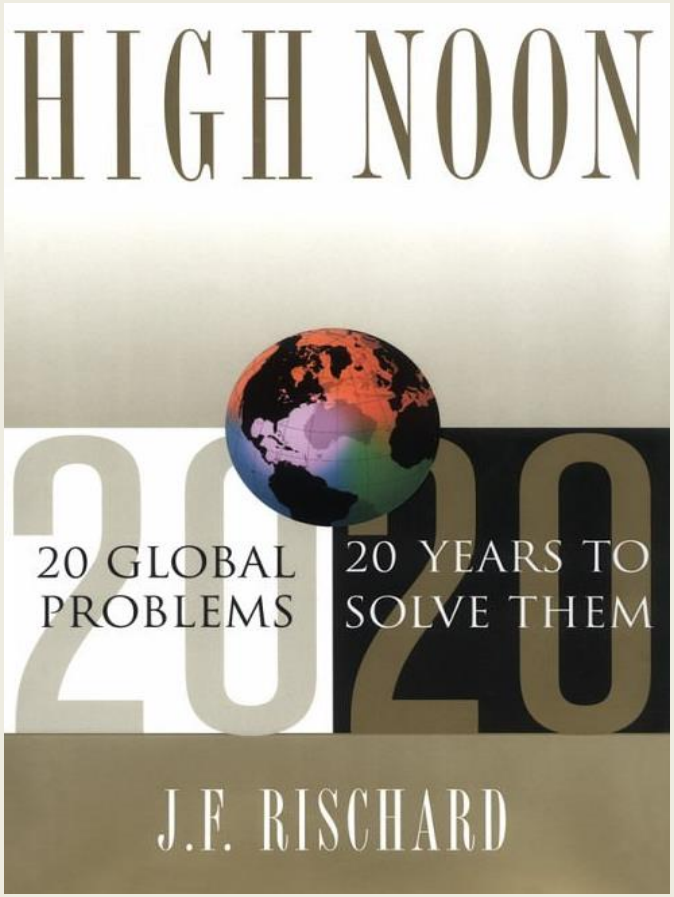
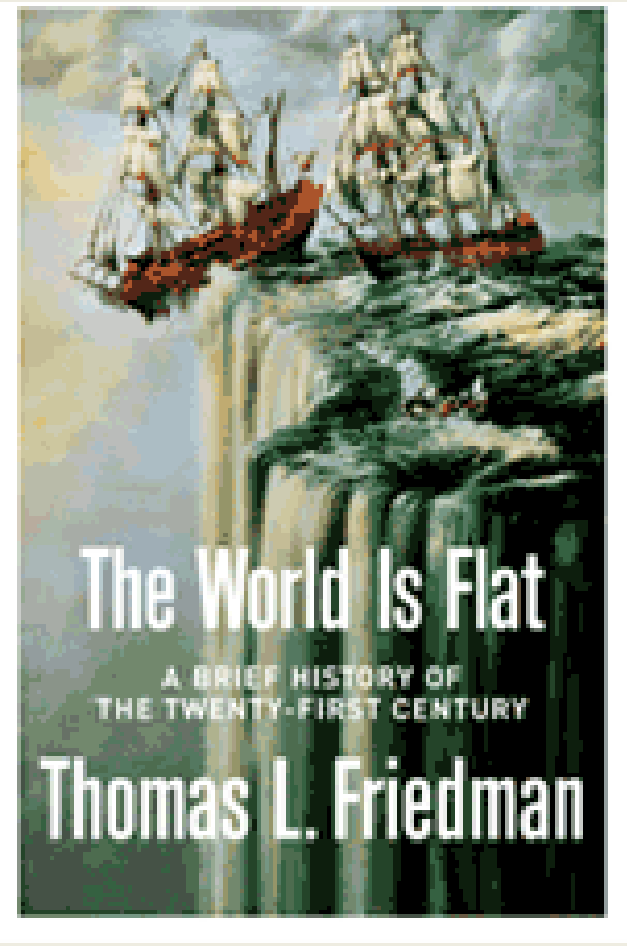
The Globally Interconnected 21st Century



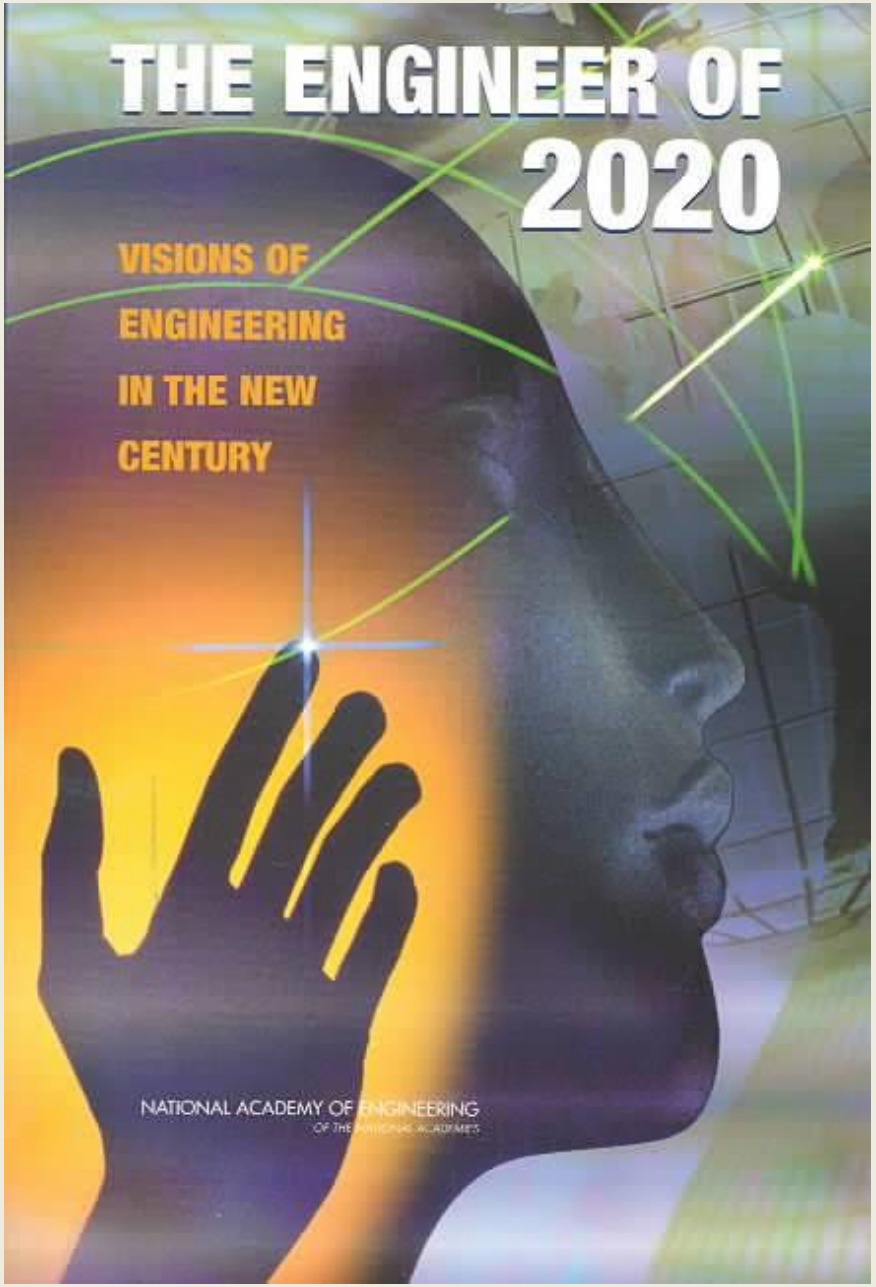
Basic Books

New York, 2002

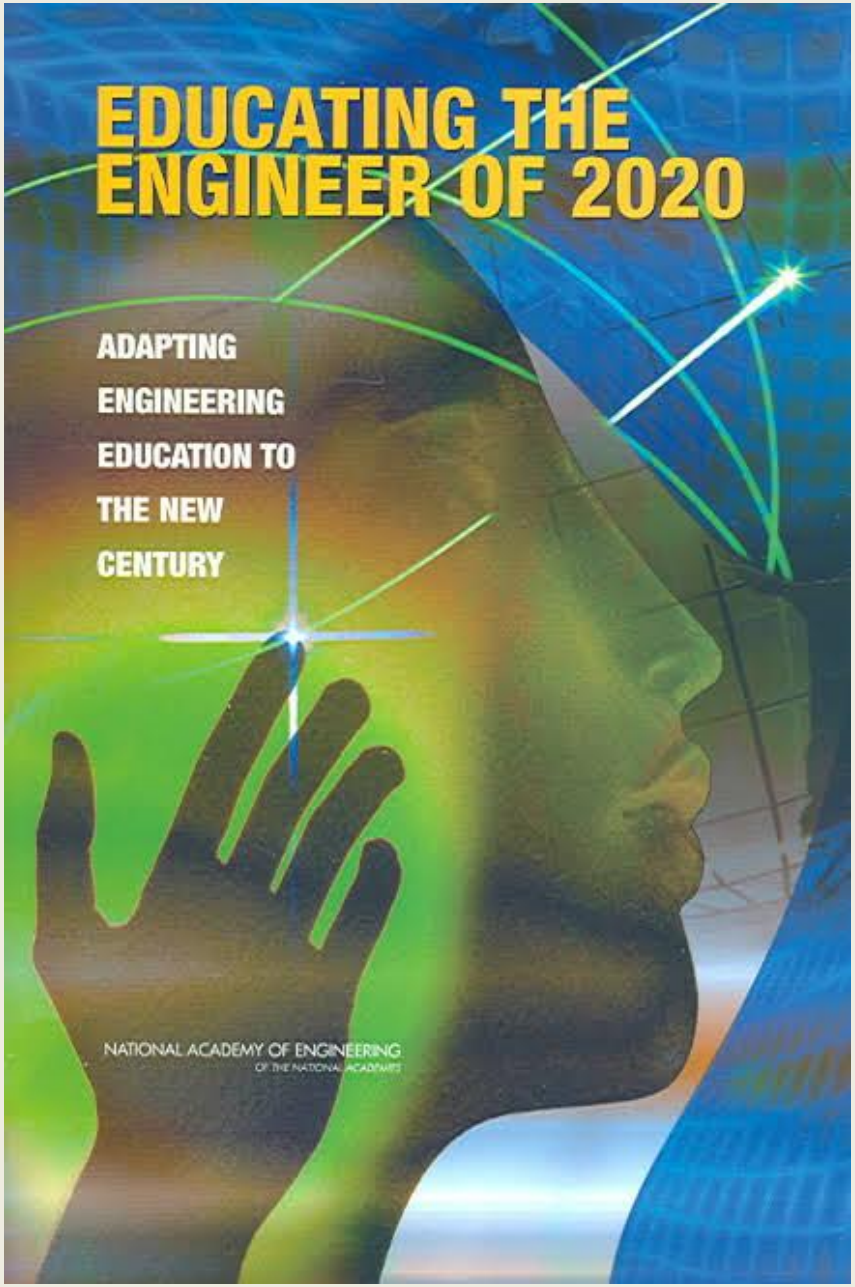


NY Times columnist on Globalization, 2004

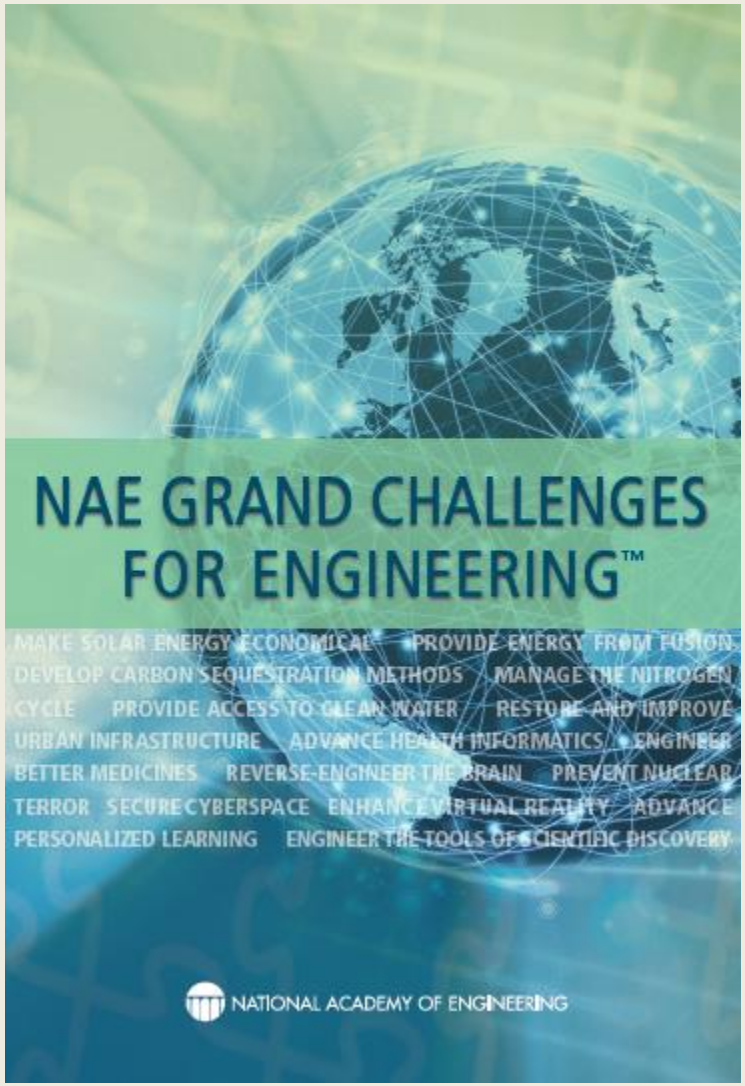
NAE Report 2004



NAE Report 2005



NAE Report 2008



INSPIRE

CHALLENGE

EDUCATE

http://www.engineeringchallenges.org/File.aspx?id=11574&v=34765dff

An Inspiring Definition of Engineering

Courtesy of NAE President C. Dan Mote

Engineers **Create Solutions** for the **Welfare of Humanity** and the **Needs of Society**

21st Century Engineering Achievements

What will be the **engineering achievements** in the 21st century?

Is this a even good question to ask?

Vision for Engineering in the 21st Century

Vision: Continuation of **life** on the **planet**, making our world more **sustainable, secure, healthy,** and **joyful**

Goals: Grand Challenges for Engineering

Objectives: 1. R & D Effort - Advance the Frontiers
2. Talent Building – Inspire the Next Generation

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NAE GRAND CHALLENGES FOR ENGINEERING

Sustainability

Energy
Environment
Global Warming

Security

Reducing Vulnerability to
Human and Natural Threats

Health

Improve Medicine and
Healthcare Delivery

Joy of Living

Expand and Enhance
Human Capability

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NAE's Engineering Grand Challenges

Make Solar Energy Economical

Provide Energy From Fusion

Develop Carbon Sequestration Methods

Manage the Nitrogen Cycle

Provide Access to Clean Water

Restore and Improve Urban Infrastructure

Advance Healthcare Informatics

Engineer Better Medicines

Reverse Engineer the Brain

Prevent Nuclear Terror

Secure Cyberspace

Enhance Virtual Reality

Advance Personalized Learning

Engineer the Tools of Scientific Discovery

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National Science Foundation
WHERE DISCOVERIES BEGIN

A New Vision for Center-Based Engineering Research

Committee on a Vision for the Future of Center-Based Multidisciplinary Engineering Research

National Materials and Manufacturing Board

Division on Engineering and Physical Sciences

National Academy of Engineering

A Report of

The National Academies of

SCIENCES · ENGINEERING · MEDICINE

THE NATIONAL ACADEMIES PRESS

Washington, DC

www.nap.edu

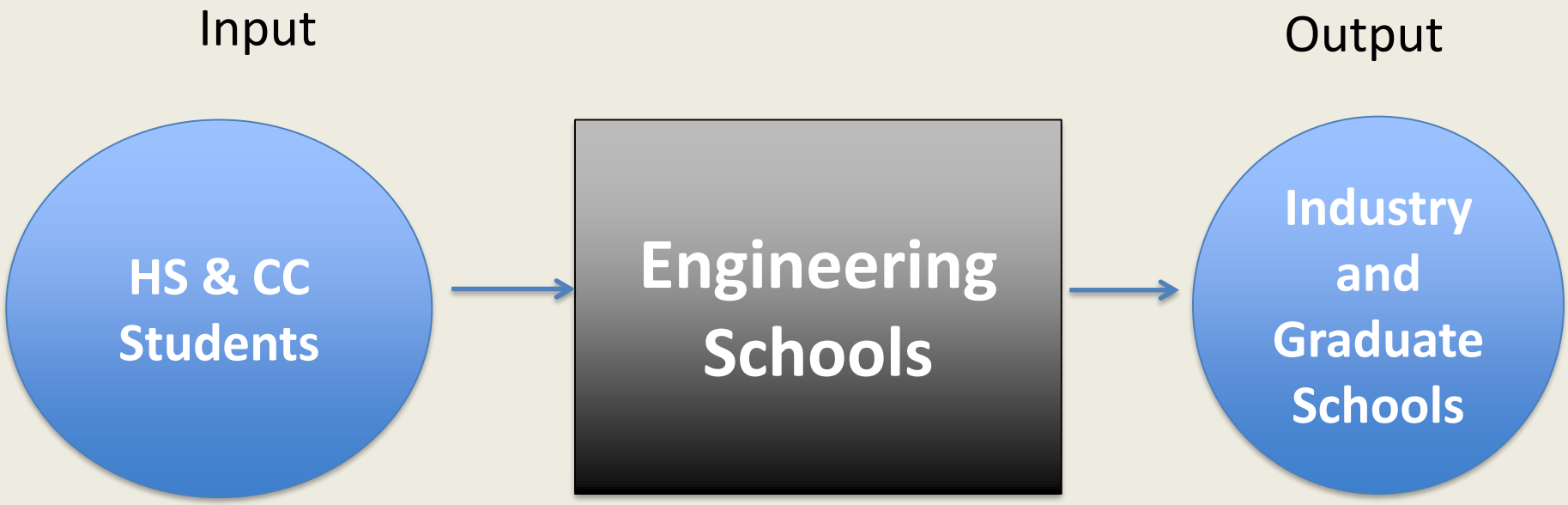
https://www.nap.edu/catalog/24767/a-new-vision-for-center-based-engineering-research

RECOMMENDATIONS:

The National Science Foundation should re-invigorate the Engineering Research Center concept by addressing grand-challenge-like problems whose solutions offer the greatest benefits for society and by adhering to the use of team-research and value-creation best practices, fewer administrative burdens, and greater investment and prestige to attract the superb, diverse talent required.

These "convergent engineering research centers (CERCs)" address the grand challenges facing society by leveraging the convergence of science, engineering, medical, and—importantly—social science disciplines to accelerate the discovery of new knowledge, create of new methods and tools, new materials and develop new products

Mismatch



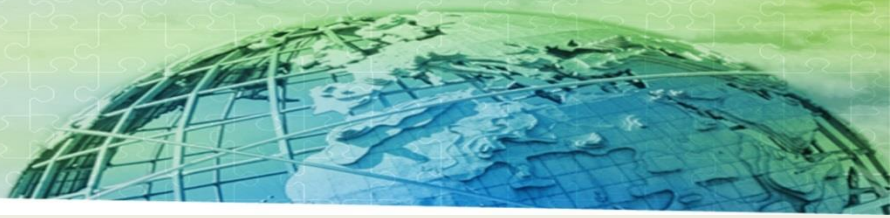
Motivation and Inspiration
Context and Relevance
Pathways not just Pipeline

Inertia
Bureaucratic
Disconnected

Global/Multicultural
Entrepreneurial
Multidisciplinary

NAE Grand Challenges Scholars Program

5 Competencies



- **Research/Creativity** : Mentored research or project experience to enhance technical competence
- **Multidisciplinarity** : Understanding of the multidisciplinary character of implementable solutions
- **Business/Entrepreneurship** : Understanding that viable business models are necessary for successful implementation
- **Global/Multicultural** : Understanding that serious consideration of cultural issues is mandatory for all viable solutions
- **Social consciousness** : Motivation to address societal problems, often gained through service learning, because serving people and the planet is the vision served by the Grand Challenges

Grand Challenges Scholars Program

- **Research/Creativity : *Depth***
- **Multidisciplinarity : *Breadth***
- **Business/Entrepreneurship : *Viability***
- **Global/Multicultural : *Planetary Vision***
- **Social consciousness : *Desirability***

Engineering+

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NAE GRAND CHALLENGES SCHOLARS PROGRAM

Grand Challenges : A Global Movement

Outcomes-based and Flexible --- NOT Prescriptive!

GCSP is a combined curricular, co-curricular, and extracurricular program with five competencies especially designed to prepare students to address major global challenges facing society in this century.

Each participating institution creates its own unique realization of how the competencies are implemented.

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Grand Challenges : A Global Movement

The programs are designed to ensure **coherence and connectivity across five competencies and a Grand Challenge theme**.

Program elements are driven by the power of the idea of the 21st century engineer, with flexibility afforded to institutions for execution.

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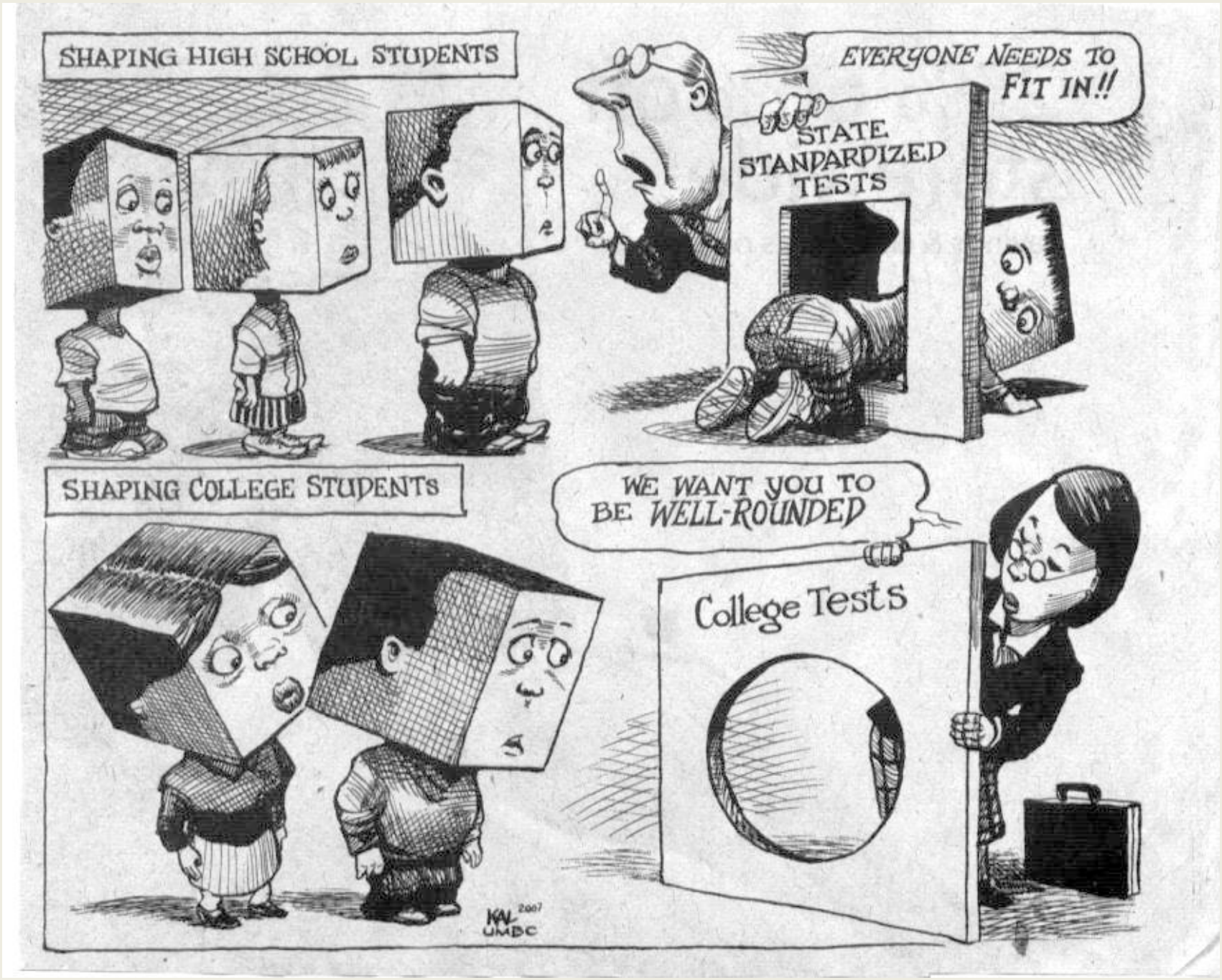

SHAPING HIGH SCHOOL STUDENTS
EVERYONE NEEDS TO FIT IN!!
STATE STANDARDIZED TESTS
SHAPING COLLEGE STUDENTS
WE WANT YOU TO BE WELL-ROUNDED
College Tests
KAL 2007 UMBC

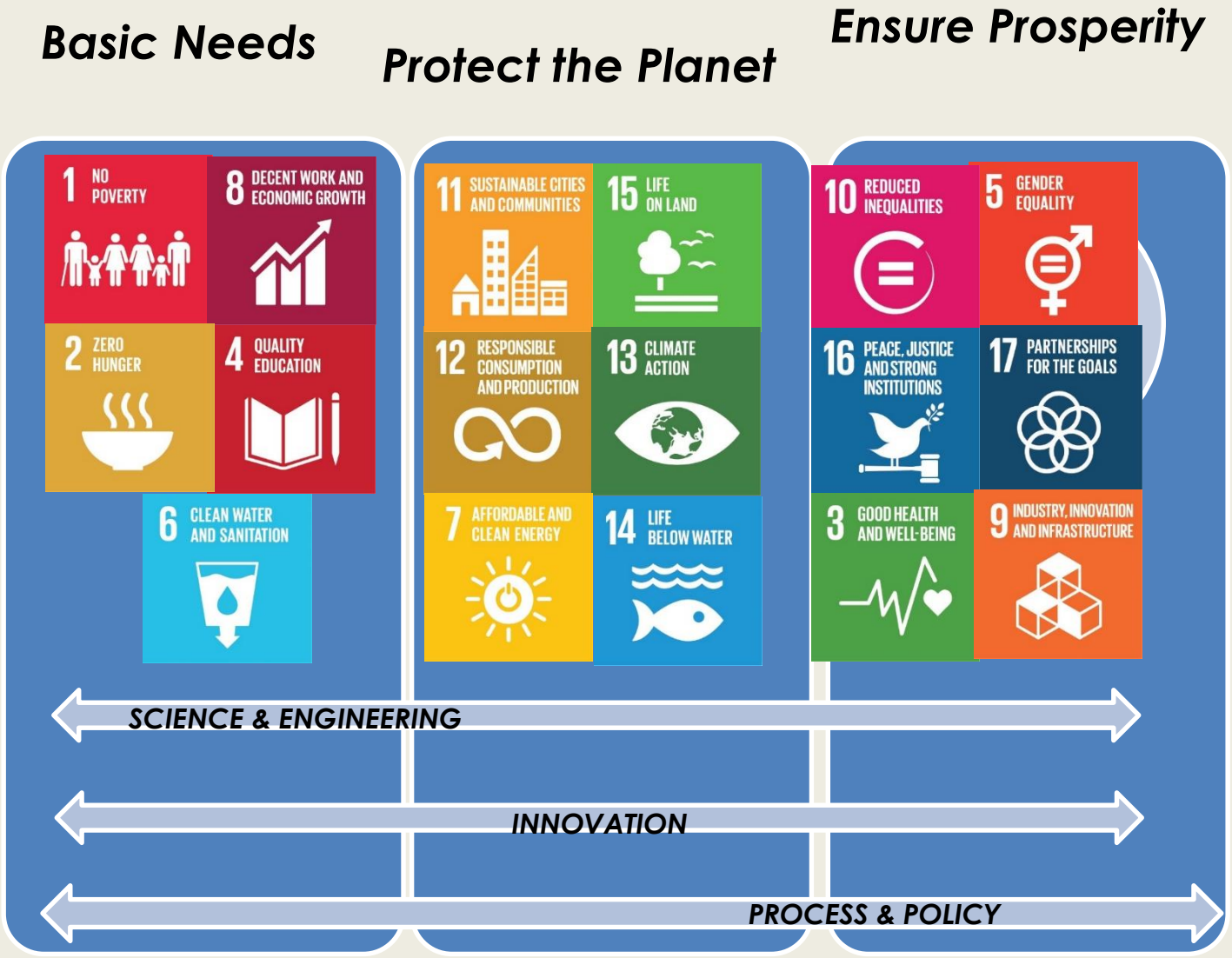
Synergy between

UN Sustainable Development Goals

And

Global Grand Challenges for Engineering

UN Sustainable Development Goals 2030



ENABLERS: Science, Engineering, Innovation & Policy

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SUSTAINABLE DEVELOPMENT GOALS

SUSTAINABLE DEVELOPMENT GOALS

6 CLEAN WATER AND SANITATION

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- Provide Access to Clean Water
- Restore and Improve Urban Infrastructure
- Manage the Nitrogen Cycle

SUSTAINABLE DEVELOPMENT GOALS

7 AFFORDABLE AND CLEAN ENERGY

NAE GRAND CHALLENGES FOR ENGINEERING
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- Make Solar Energy Economical
- Provide Energy from Fusion
- Develop Carbon Sequestration Methods

SUSTAINABLE DEVELOPMENT GOALS

11 SUSTAINABLE CITIES AND COMMUNITIES

NAE GRAND CHALLENGES FOR ENGINEERING
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- Provide Access to Clean Water
- Restore and Improve Urban Infrastructure
- Make Solar Energy Economical

SUSTAINABLE DEVELOPMENT GOALS

13 CLIMATE ACTION

NAE GRAND CHALLENGES FOR ENGINEERING
NATIONAL ACADEMY OF ENGINEERING

- Make Solar Energy Economical
- Provide Energy from Fusion
- Develop Carbon Sequestration Methods

NAE Grand Challenges Scholars Program

Vision Mandates Global Solutions

- Captures needs of people and society
- Solutions depend on locale
- **Students are inspired by the Grand Challenges**
- **Grand Challenges Scholars Program – Key to "Talent Building"**
  - An entré for all as it is uniquely designed by each institution
- **Employers everywhere are looking for GCSP-type students**
- **"We" are all in this together**

NAE Grand Challenges Scholars Program

The Role of the NAE

- Champion of the Vision
- Convener of the Stakeholders
- Community Influencer/Builder
- Change Agent

to Catalyze a Global Movement

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NAE GRAND CHALLENGES SCHOLARS PROGRAM

Opportunities for Materials Sciences and Engineering to Shine

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NAE GRAND CHALLENGES FOR ENGINEERING

Sustainability

Provide Access to Clean Water
Provide Clean Energy

Security

Improve Urban Infrastructure

Health
Engineer Better Medicines

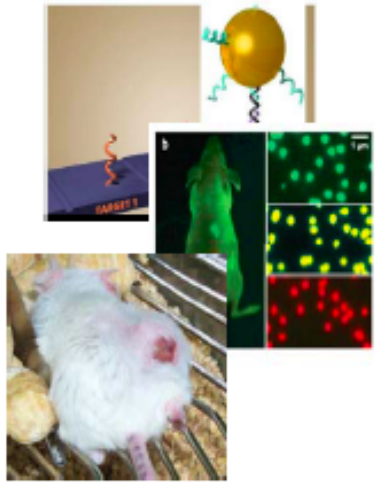
Examples of Opportunities for Nanomaterials

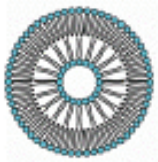
Nanotechnology and Cancer

http://nano.cancer.gov/learn/understanding/video_journey.asp

Cancer Nanotechnology: The Opportunity

- Combine power of innovation in nano-materials and cancer biology to develop new solutions in cancer
- Detect disease *before* health has deteriorated
  - Sensors
  - Imaging
- Deliver therapeutics
  - Local delivery
  - Improved efficacy
  - Post-therapy monitoring
- Develop research tools to enhance understanding of the disease



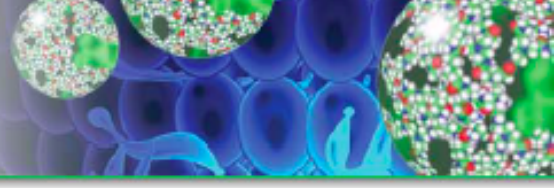

Liposome


Gold nanoshell


Dendrimer

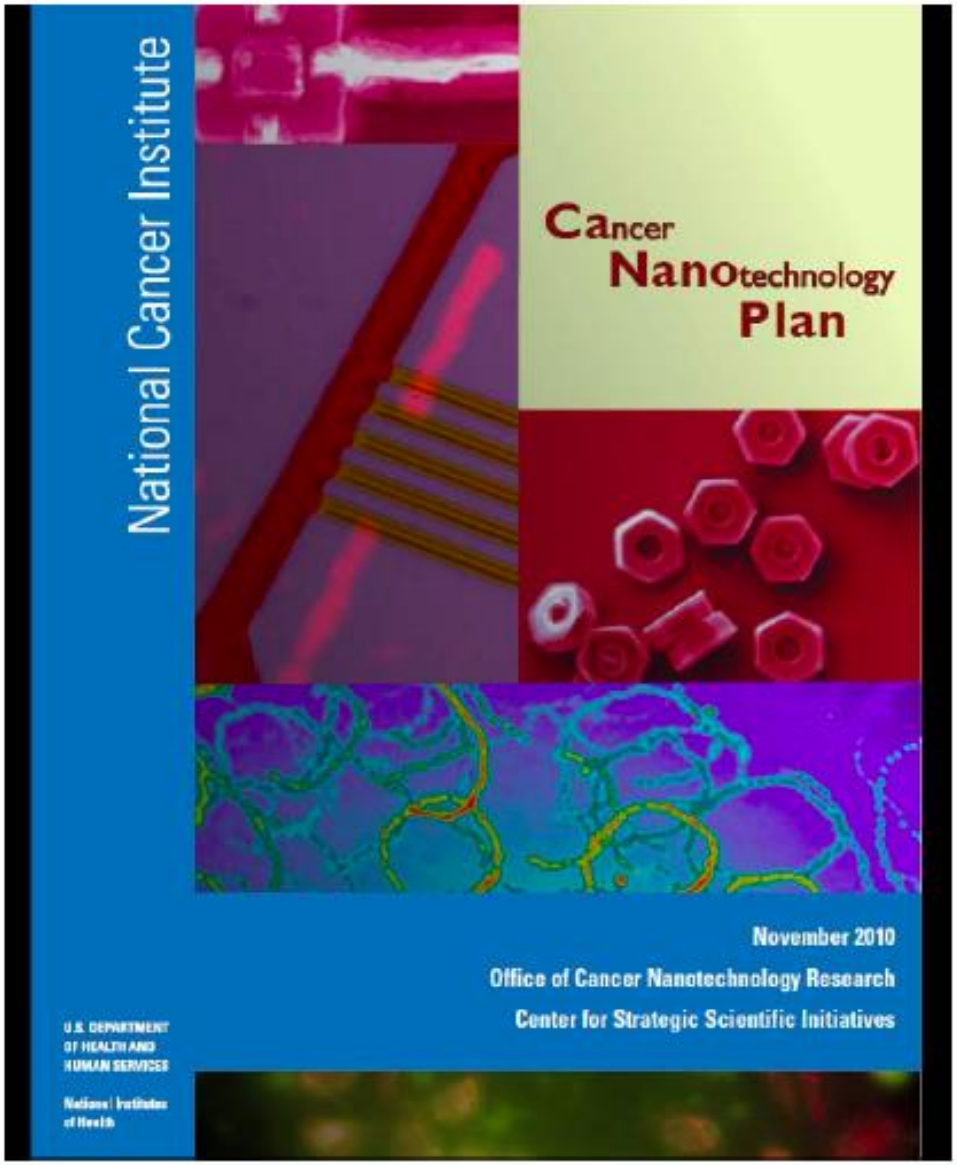

Quantum Dot

Why Nanotechnologies for Cancer?



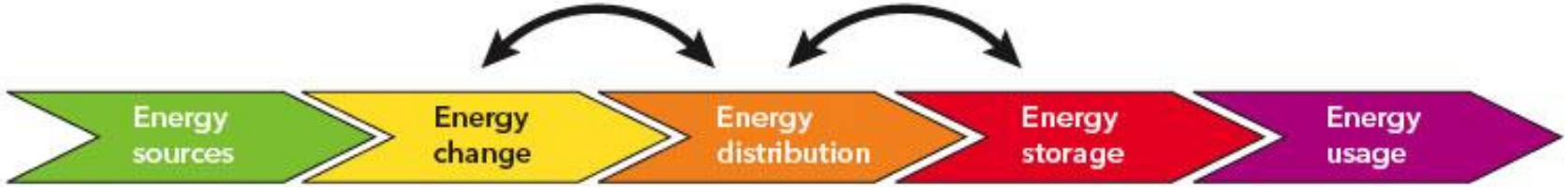
- Cancer can generally be successfully treated – if diagnosed early
- Cancer is exceedingly complex (potentially hundreds of genomic changes – possibly thousands of proteomic changes to measure for diagnosis) – power of multiplexed detection is needed
- Specific delivery of therapies to targeted cancer cells is critical – now and in the future
- Theranostic functions are necessary for diagnosing and treating cancer (need to detect – deliver – report – monitor – re-deliver)
- Probing and understanding changes in tissues/microenvironments are crucial to preventive strategies for cancer

Forward Strategies



Nanotechnology in Energy

- Nanotechnologies provide the potential to enhance energy efficiency across all branches of industry and to economically leverage renewable energy production through new technological solutions and optimized production technologies. Nanotechnology innovations could impact each part of the value-added chain in the energy sector-Sources, Conversion, Distribution, Storage and Usage



Energy sources

Regenerative

Photovoltaics: Nano-optimized cells (polymeric, dye, quantum dot, thin film, multiple junction), antireflective coatings

Wind Energy: Nano-composites for lighter and stronger rotor blades, wear and corrosion protection nano-coatings for bearings and power trains etc.

Geothermal: Nano-coatings and -composites for wear resistant drilling equipment

Hydro-/Tidal Power: Nano-coatings for corrosion protection

Biomass Energy: Yield optimization by nano-based precision farming (nanosensors, controlled release and storage of pesticides and nutrients)

Fossil Fuels

Wear and corrosion protection of oil and gas drilling equipment, nanoparticles for improved oil yields

Nuclear

Nano-composites for radiation shielding and protection (personal equipment, container etc.), long term option for nuclear fusion reactors

Energy change

Gas Turbines

Heat and corrosion protection of turbine blades (e.g. ceramic or intermetallic nano-coatings) for more efficient turbine power plants

Thermoelectrics

Nanostructured compounds (interface design, nanorods) for efficient thermoelectrical power generation (e.g. usage of waste heat in automobiles or body heat for personal electronics (long term))

Fuel Cells

Nano-optimized membranes and electrodes for efficient fuel cells (PEM) for applications in automobiles/mobile electronics

Hydrogen Generation

Nano-catalysts and new processes for more efficient hydrogen generation (e.g. photoelectrical, elektrolysis, biophotonic)

Combustion Engines

Wear and corrosion protection of engine components (nano-composites/-coatings, nano-particles as fuel additive etc.)

Electrical Motors

Nano-composites for superconducting components in electro motors (e.g. in ship engines)

Energy distribution

Power Transmission

High-Voltage Transmission: Nanofillers for electrical isolation systems, soft magnetic nano-materials for efficient current transformation

Super Conductors: Optimized high temperature SC's based on nanoscale interface design for loss-less power transmission

CNT Power Lines: Super conducting cables based on carbon nanotubes (long term)

Wireless Power Transmission: Power transmission by laser, microwaves or electromagnetic resonance based on nano-optimized components (long term)

Smart Grids

Nanosensors (e.g. magneto-resistive) for intelligent and flexible grid management capable of managing highly decentralised power feeds

Heat Transfer

Efficient heat in- and outflow based on nano-optimized heat exchangers and conductors (e.g. based on CNT-composites) in industries and buildings

Energy storage

Electrical Energy

Batteries: Optimized Li-ion-batteries by nanostructured electrodes and flexible, ceramic separator-foils, application in mobile electronics, automobile, flexible load management in power grids (mid term)

Supercapacitors: Nanomaterials for electrodes (carbon-aerogels, CNT, metall(-oxides) and elektrolytes for higher energy densities)

Chemical Energy

Hydrogen: Nanoporous materials (organometals, metal hydrides) for application in micro fuel cells for mobile electronics or in automobiles (long term)

Fuel Reforming/Refining: Nano-catalysts for optimized fuel production (oil refining, desulphurization, coal liquefaction

Fuel Tanks: Gas tight fuel tanks based on nano-composites for reduction of hydrocarbon emissions

Thermal Energy

Phase Change Materials: Encapsulated PCM for air conditioning of buildings

Adsorptive Storage: Nano-porous materials (e.g. zeolites) for reversible heat storage in buildings and heating nets

Energy usage

Thermal Insulation

Nanoporous foams and gels (aerogels, polymer foams) for thermal insulation of buildings or in industrial processes

Air Conditioning

Intelligent management of light and heat flux in buildings by electrochromic windows, micro mirror arrays or IR-reflectors

Lightweight Construction

Lightweight construction materials using nano-composites (carbon nanotubes, metal-matrix-composites, nano-coated light metals, ultra performance concrete, polymer-composites)

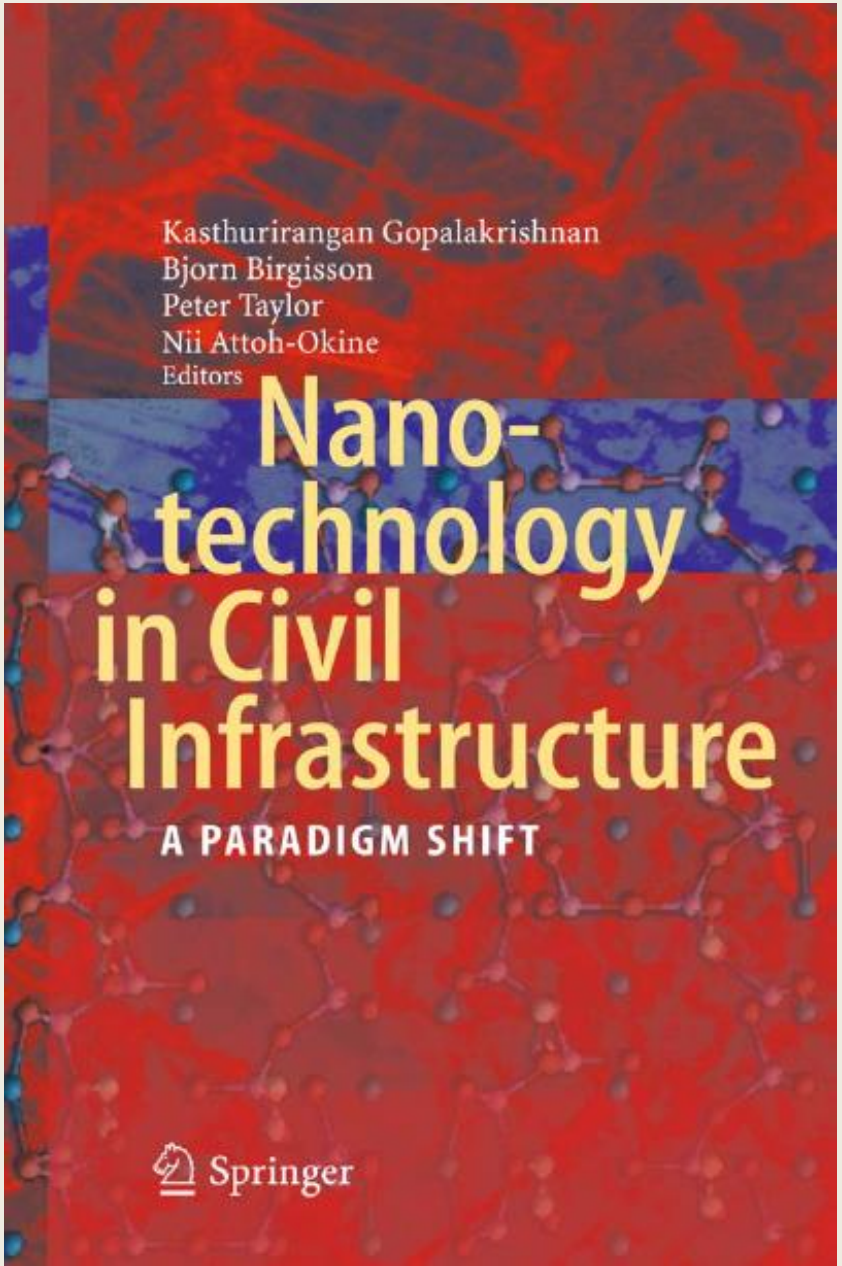
Industrial Processes

Substitution of energy intensive processes based on nanotech process innovations (e.g. nano-catalysts, self-assembling processes etc.)

Lighting

Energy efficient lighting systems (e.g. LED, OLED)

2011 Report


Kasthurirangan Gopalakrishnan
Bjorn Birgisson
Peter Taylor
Nii Attoh-Okine
Editors
Nano-technology in Civil Infrastructure
A PARADIGM SHIFT
Springer

Nanotechnology and Water Treatment

Examples of nanostructured and nanoreactive membranes for use in water filtration

Membrane	Pollutant	Reference
Nanostructured membranes		
Carbon nanotubes	Bacteria and viruses	Srivastava et al. (2004)
Nanocapillary array membranes (NCA)	*NT	Chatterjee et al. (2005)
Nanoreactive membranes		
Alumina membrane formed from A-alumoxane	Synthetic dyes	DeFriend et al. (2003)
Alumina membranes functionalized with poly(styrene sulfonate) or poly(allylamine hydrochloride)	Divalent cations	Stanton et al. (2003)
Silica and cellulose-based membranes functionalized with amino acid homopolymers	Metal ions	Bhattacharayya et al. (1998); Ritchie et al. (1999, 2001)
Polycarbonate track-etched membranes functionalized with amino acid homopolymers	Metal ions	Hollman and Bhattacharayya (2004)
Pt/Fe laden cellulose acetate film	Trichloroethylene (TCE)	Meyer et al. (2004)
Zero-valent Fe laden cellulose acetate membrane	TCE	Wu et al. (2005)
Ni/Fe or Pd/Fe laden polyacrylic acid/polyether sulfone composite membranes	TCE	Xu et al. (2005a)
Ni/Fe laden cellulose acetate membrane	TCE	Wu and Ritchie (2006)
Alumina or polymeric membranes with gold nanoparticles	4-nitrophenol	Dotzauer et al. (2006)
Polymer-impregnated ceramic TiO_2 filters	Polycyclic aromatic hydrocarbons (PAHs)	Arkas et al. (2006)
Polymer-impregnated ceramic alumina and silicon-carbon filters	Trihalogen methanes, PAHs, pesticide	Allabashi et al. (2007)

Thank You!!